GALCIT REPORT NO.________

GUGGENHEIM AERONAUTICAL LABORATORY

CALIFORNIA INSTITUTE OF TECHNOLOGY

SHORT TIME COMPRESSIVE CREEP IN 75S-T6 AND 25S-T6 ALUMINUM ALLOY SHORT COLUMNS

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FORM AL-5 6M 2-49

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Thesis by

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In Partial Fulfillment of the Requirements
For the Degree of
Aeronautical Engineer

California Institute of Technology
Pasadena, California

1952

ACKNOWLEDGEMENTS

The author wishes to express his gratitude to the following people whose contributions made this thesis possible; to Dr. E. E. Sechler for his timely advice and guidance; to Dr. D. S. Clark, and Dr. Y. C. Fung for their helpful suggestions; to Mr. Milton J. Woods for his cooperation in the design of the testing machine, and photography; to Mr. Marvin E. Jessey for assistance with the electrical problems; to Mr. C. A. Bartsch and his staff for their skillful machining of the test apparatus, and test specimens; to Mrs. Betty L. Woods for presentation of data; to R. J. Kauffman, Lt. USN, and R. Gaibler, Lt. USN, for their cheerful cooperation during the entire investigation; to Mrs. June B. Royce for typing the thesis; and to his wife, Mrs. Hazel R. Thatcher, for her cheerful acceptance of the hardships encountered during the preparation of this thesis.

SUMMARY

The creep characteristics of some of the light metal alloys at high temperature and stress were investigated when subject to; (1) Tension, (2) Short Column Compression, (3) Long Column effect. The tension and long column aspects are covered in the theses of R. J. Kauffman and R. Gaibler respectively. This thesis concerns the short-time creep of short columns of 25S-T6 and 75S-T6 aluminum alloy, subjected to large compressive loads, and temperatures of 450°, 500°, and 550°F. The columns were circular in cross section, and had an effective slenderness ratio of 25.5.

It was found that 75S-T6 was superior to 25S-T6 at 450°F and, that at that temperature, 75S-T6 short columns could withstand a stress of 14,500 psi, however due to creep, failure occurred in approximately 45 seconds. At a temperature of 500°F, 25S-T6 was found to be superior, and withstood a stress of 11,000 psi for approximately 60 seconds before creep failure occurred. The load carrying ability of the two alloys was about the same at 550°F with both materials withstanding 8,000 psi for approximately 60 seconds.

It is commonly believed that aluminum alloys are of little value at temperatures as high as 550°F, however contrary to this belief, this investigation shows that short columns of the two alloys tested can carry a large compression load if the time of duration is short.

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I. INTRODUCTION

With the advent of high speed aircraft and guided missiles, the designer is faced with the ever increasing problems of higher operating temperatures in the engine, and aerodynamic heating of the skin of the aircraft or missile. To further complicate the problem, there is the ever present demand, especially from the military, for higher performance, which immediately requires minimum weight design. Therefore the designer must have available the creep characteristics, at high temperature and high stress, of the light metal alloys.

Considerable research has been done on the creep of metals[1], however as concerns the light metal alloys, the investigations have concerned long time creep, i.e., creep at high temperature and low stress, or at low temperature and high stress. Further the bulk of the investigations have been concerned with creep in tension, with little having been done about creep in compression, or the effect of creep on columns. The long time creep of some creep-resistant nickel-chromium alloys subjected to compressive stress, has been shown to be similar to tensile creep[2], however here again the investigation concerned only a few metals, and totally ignored the regime of short-time creep.

This investigation is concerned with the short-time creep of some of the light metal alloys subject to; (1) Tension; (2) Short Column Compression, and (3) Long Column Effect. The short-time compressive creep aspect will be treated in this thesis, whereas the tension, and

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(1) See Bibliography

long column aspects of the investigation are being reported by R. J. Kauffman, and R. Gaibler respectively, as noted in the bibliography.

The short column creep tests were conducted on 75S-T6 and 25S-T6 aluminum alloy columns, with an effective slenderness ratio of 25.5, subjected to temperatures of 450°F to 550°F, and stresses close to the critical stress. The time to failure in general is less than 10 minutes, which limits the use of the curves to the design of some type of guided missile, rather than aircraft.

The tests were conducted at the Guggenheim Aeronautical Laboratory, California Institute of Technology, Pasadena, California, under the guidance of Dr. E. E. Sechler and with the assistance of R. J. Kauffman, Lt. USN, and R. Gaibler, Lt. USN.

II. EQUIPMENT

At the time the subject for this thesis was conceived, there was no suitable creep testing equipment available at California Institute of Technology. Therefore, after considering what the minimum requirements of the equipment could be, the following specifications were decided on; (1) a lever type, constant load testing machine, capable of applying an axial load of 6,500 pounds on the specimen, both in tension and compression; (2) a furnace capable of maintaining the specimen at a temperature of 550°F $\pm$ 5°F, with the heat being applied in such a manner as to keep the gradient over the specimen less than 10°F; (3) a method of strain measurement accurate to 0.0005 in./in.

Fig. 1. shows the general arrangement of the equipment. The frame and fittings are made of mild steel, except for such parts as the knife edges and rings, which are hardened steel. The knife edges are spaced in the lever arm so as to give a mechanical advantage of 10. A ball-socket joint at the lower plate eliminates any eccentric loading of the vertical steel shaft. In order to apply compressive loads to the specimen, a reversing cage was necessary (See Fig. 2.). This compression cage is made of mild steel with hardened end plates. The end plates have a one inch radius spherical surface, for seating the specimen.

In order to decrease the conduction of heat in the vertical steel shaft, two heat insulating joints were needed, one just above, and the other just below, the upper and lower plates of the furnace respectively. Insulation is obtained through a dead air space in the heat

joint, plus a 3/4 inch transite washer between the steel load transmitting surfaces.

The vertical members of the frame have 13 holes spaced two inches apart, to allow for positioning the platform holding the furnace, and also the lower plate which restrains the ball joint. In addition, the ring which supports the middle knife edge and the vertical shaft which pierces the lower plate, are both amply threaded to allow for centering the specimen in the furnace.

The furnace consists of a transite pipe, split down the middle and insulated by two inches of rock wool on the sides, and four inches of rock wool above and below the transite ends. Exterior to the rock wool is a half cylinder of Dural sheet, which connects to the upper and lower 1/4 inch steel plates. Inside the transite shell is a 1/4 inch layer of asbestos for protection of the transite, and inside the asbestos is a stainless steel liner, to obtain maximum radiation of heat. The two halves of the furnace are connected with a piano hinge, and overlap is provided between the two halves to cut down heat loss through the joints of the furnace. Details of the furnace are shown in Figs. 3, 4, 5, and 6.

The original design of the furnace called for 16 vertical elements, equally spaced as shown in Fig. 7. The wiring was done so as to provide high, medium, and low heat control of the furnace. When on high heat four sets, of four elements in series, are in parallel. On medium heat two sets, of four elements in series, are in parallel, and on low heat two sets, of eight elements in series, are paralleled. Subsequent tests on the furnace showed this arrangement gave adverse

temperature gradients on the specimen, therefore additional ring shape elements were added to the top and bottom surfaces of the furnace box. The input to the side elements is approximately 2,000 watts on high heat, and 500 watts on low heat. The input to the lower ring element is 250 watts on both high and low, and the upper ring element uses approximately 62 watts on both high and low heat.

The temperature of the furnace was controlled by using a Sim-Ply-Trol controlling pyrometer to operate a relay, which in turn controlled the power to the elements. The control board is shown in Fig. 1.

Measurement of deformations was accomplished by two, eight-power telescopes, spaced four inches apart vertically, mounted on the furnace (Fig. 1), and reading directly the movement of two scales, fastened to the upper and lower inner plates of the compression cage (Fig. 2). The telescopes were altered in order to permit focusing on the scales; this was done by inserting a brass sleeve between the eyepiece and body of the telescope (Fig. 8). A cross hair was mounted in the brass sleeve to provide a reference point. The scales are standard 1/4 inch steel scales whose smallest division is 0.01 inches, however, due to the magnification obtained in the telescope, it is possible to measure 0.001 inch motion of the scale accurately. Since the gauge length of the specimen is five inches, the measurement of strain is accurate to 0.0002 in./in.

The light source consists of a bulb mounted in a plastic impregnated fiber holder, which was inserted in the light source hole cut

in the furnace.

Details of the telescope and light source mountings are shown in Figs. 5 and 6.

II. TESTING MATERIAL

The materials tested in this investigation were 75S-T6 and 25S-T6 aluminum alloys. These particular alloys were considered particularly desirable, since they are extensively used in the aircraft industry.

The 75S-T6 specimens were machined from commercial, 5/8 inch round, forged stock. The 25S-T6 was machined from a forged propeller blade, obtained from the Cooperative Wind Tunnel. The propeller had not been in previous use at the wind tunnel.

Specifications for the specimens used in this investigation are shown in Fig. 9.

The room temperature mechanical properties of both alloys were determined from tests run in a Baldwin-Southwork, Universal, 300,000 pound testing machine, with a Tate-Emery load indicator. The deformations were measured with a Huggenberger extensometer. Results of these tests are shown in Figs. 10 through 13 and tabulated in Table I. The values obtained agree favorably with accepted values.

[illegible]

Before assembly of the testing machine, all elements of the load transmitting system were weighed accurately to one ounce, in order to determine the load on the specimen due to the dead weight of these elements. The testing machine was then assembled, the furnace put in place, and a specimen placed in the compression cage.

The measuring system was checked first and it was found that the field of vision of the telescope was only 0.08 inches, which was somewhat smaller than had been anticipated. Therefore in order to provide reference points on the scale, miniature X's, O's, and I's were etched between each 0.05 inch marker of the scale. The scale was also chrome plated to provide easier readability. With these two alterations, the measuring system proved to be adequate.

The temperature gradient in the specimen was determined by using three iron-constantan thermocouples, located at the top, in the center, and at the bottom of the specimen. The thermocouple for the controller was placed at the center of the specimen. These thermocouples were wired to the specimen with very light iron wire. Another thermocouple was silver soldered to the specimen, in order to check the contact of the thermocouples which were wired to the specimen, and it was found that wiring the thermocouples gave the same temperatures. With these thermocouples in place, the furnace was brought up to temperature using high heat. The time required to obtain 550°F on the specimen was approximately 12 minutes, the time being somewhat less for the lower temperatures. The furnace was

then allowed to operate one hour at temperature before checking the gradient. The temperature of the thermocouples was determined using a Leeds and Northrup potentiometer. The gradient over the specimen was checked at 450°F, 500°F, and 550°F, with the heat control set on both high and low, and with the upper ring element connected and disconnected. The most favorable gradient was obtained with the heat control set on low, and with the top ring element inoperative. In this condition the gradient was 4°F from top to bottom of the specimen at 550°F. The gradient was appreciably higher with the furnace set on high heat, and also when the top ring element was connected and the heat control on either high or low. The variation of temperature at any one point of the specimen, was less than one degree. During these temperature survey tests, it was found that by making a final adjustment of the dial setting on the Sim-Ply-Trol controlling pyrometer approximately 30 minutes before the test began, the desired temperature on the specimen could be obtained within one degree.

The effective slenderness ratio of the test specimen was determined by first calculating the end fixity of the specimen. This was accomplished by; (1) determining the critical stress for a standard test specimen at room temperature; (2) determining the tangent modulus corresponding to this critical stress; and (3) calculating the end fixity from Engessers' equation,[3] $\frac{P}{A} = C \frac{\pi^2 E_t}{(L/\rho)^2}$ where;

$\frac{P}{A}$ = ultimate strength of axially loaded column, lb. per sq. in.

L = length of column, inches

E_T = tangent modulus corresponding to $\frac{P}{A}$, lbs. per sq. in.

ρ = least radius of gyration, inches.

The critical stress, or ultimate strength, of a 75S-T6 test specimen was determined, using a Baldwin-Southwark, Universal, 300,000 lb. testing machine. The end plates of the compression cage were placed between the specimen, and the heads of the testing machine, and a standard stress-strain test run. The results are plotted in Fig. 14. Using figure 12, the tangent modulus corresponding to the critical stress for the test specimen was determined. It is now possible to solve for the end fixity in Engessers' equation. Having c, the effective slenderness ratio is $\frac{L'}{\rho} \equiv \frac{L}{\sqrt{c}\,\rho}$ (4). The end fixity was found to be 2.46, and the effective slenderness ratio is 25.5. The critical effective slenderness ratio, based on 0.2 percent offset yield stress, was calculated to be 54.7, using the equations for short columns from Reference 4. Therefore the columns tested are well within the short column range.

Formal testing of the specimen was now begun. The thermocouple for the Sim-Ply-Trol controller was wired to the center of the specimen, with another thermocouple placed close beside it, in order to check the actual temperature on the specimen before the test began. This was found to be quite necessary in that variations of the ambient air temperature, affected the temperature of the specimen(5), and corrective setting of the Sim-Ply-Trol indicator was necessary to obtain the desired temperature for the test. Proper alignment of the scales with the telescopes was now accomplished, and the furnace closed. The weight necessary to put the desired stress on the specimen was determined to $\pm$ 0.01 lbs., and placed on the

loading pan, which was supported by a hydraulic jack (See Fig. 1). The furnace control was turned to high heat until the desired temperature was reached, and then turned to low heat and allowed to stabilize at the test temperature for one hour. As mentioned previously, final adjustment to the temperature was made approximately 30 minutes prior to test time, however this consisted of a $\pm$ 3°F change, so to all intents and purposes the specimen was at the desired temperature for one hour prior to test. The temperature was taken immediately before beginning the test and recorded. Scale readings were taken immediately before the load was applied, and then the loading was accomplished as smoothly as possible, by controlling the rate of descent of the hydraulic jack. The time required to apply the load was approximately five seconds, and throughout the tests an attempt was made to maintain the same loading rate. Scale readings were taken every 15 seconds, until the specimen failed. At completion of the test, the temperature was again taken, however there was never any appreciable change noted.

Several tests were made in the same manner described above, except that the scales were mounted on the specimen. This resulted in large errors in scale readings, due to rotation of the scales, depending on the direction of bending of the specimen. Therefore these tests were totally unreliable and all data obtained had to be discarded.

Tests were conducted on 75S-T6 and 25S-T6 specimens at 450°F, 500°F, and 550°F. The highest loading at each temperature was very close to the ultimate load.

V. DISCUSSION OF RESULTS

The results of tests run on 75S-T6 and 25S-T6 short columns, with an L/ρ of 25.5, are shown in Figs. 15 through 20.

Fig. 15 shows the creep characteristics of 75S-T6 at 450°F, and it can be seen that this alloy will withstand a stress of 14,500 psi, but due to creep, failure will occur in approximately 45 seconds. Decreasing the stress 500 psi increases the time to failure appreciably, so that at 13,000 psi the time to failure is in excess of 6 minutes. Figs. 16 and 17 show the creep characteristics of 75S-T6 at 500° and 550°F respectively. As in the tests at 450°F, the increase in time to failure with decrease in stress is quite rapid. The time to failure was approximately 90 seconds at a temperature of 500°F and a stress of 10,000 psi, however by decreasing the stress to 9,000 psi the time to failure was increased to approximately 8 minutes. Failure occurred in approximately 75 seconds at a temperature of 550°F and a stress of 8,000 psi, whereas at 7,000 psi the time to failure was in excess of 6 minutes.

Figs. 18, 19, and 20 are the creep curves for 25S-T6 at 450°, 500°, and 550°F respectively. These curves show the same characteristics as mentioned above for 75S-T6. It is interesting to compare the curves for 25S-T6, for which the time to failure was the shortest, with those for 75S-T6 at the three test temperatures. At 450°F, 25S-T6 failed in approximately 75 seconds under a stress of 14,000 psi, whereas for 75S-T6 the time to failure was 45 seconds with a stress of 14,500 psi. The time to failure at 500°F was approximately the same for both alloys, however 25S-T6 withstood a stress of 11,000 psi as compared to 10,000 psi for 75S-T6. At 550°F, both alloys with-

stood a stress of 8,000 psi and the time to failure was approximately the same. This clearly indicates the use of 25S-T6 rather than 75S-T6 for those applications in which the temperature is to be above 450°F.

Fig. 21 shows the results obtained in three tests of 25S-T6 specimens, under identical conditions of load and temperature. The almost exact reproducibility shown in these curves indicates fairly good instrumentation and experimental technique. The main discrepancy in the three curves is the initial strain, which can be attributed to a number of things, one of which is normal statistical variation. However it should be pointed out that from the results of some of the early tests, it was observed that variation in loading rate had a very decided effect on the initial deformation. As mentioned previously an attempt was made to maintain the same loading rate in all the tests, however this is quite impossible and can only be approached with the equipment available.

Fig. 22 is a plot of stress vs. minimum creep rate for 25S-T6 and 75S-T6, however it is of academic use only, since the period of secondary creep is very short; therefore the minimum creep rate given here cannot be used for long-time prediction of the deformation to be expected in 25S-T6 or 75S-T6 short columns. The minimum creep rate curves were plotted primarily to bring out any discrepancies in the curves of Figs. 15 through 20, however they also indicate the superiority of 25S-T6 at 500°F.

Fig. 23 shows the time at which the transition point is reached in short columns of 25S-T6 and 75S-T6, depending upon the stress and temperature. Transition point is the inflection point between the con-

stant creep and increasing creep rate, which continues up to the rupture point of the material.[4] Figs. 24 and 25 are curves giving the time required for 1.0 percent and 1.5 percent deformation to occur in 75S-T6 and 25S-T6 respectively. Figs. 23, 24, and 25 are cross plots of Figs. 15 through 20, and are intended for use in the design of missiles. For instance supposing the designer has a compression member with an L/ρ of approximately 25.5, which is to be used in a supersonic guided missile. The missile after reaching its maximum speed will, due to aerodynamic heating, be subjected to rather high temperatures. In addition short-time accelerations will be encountered, which will subject the member in question to high loads of short-time duration. Knowing the temperature, stress, and time of duration of stress, the designer can use Fig. 23, 24, or 25 to determine whether a column of 25S-T6 or 75S-T6 would be suitable for the application.

VI. CONCLUSIONS AND RECOMMENDATIONS

From the results of this experiment it was found that 75S-T6 aluminum alloy was slightly superior to 25S-T6 at 450°F, and that 75S-T6 short columns could withstand 14,500 psi for approximately 45 seconds. At 500°F, short columns of 25S-T6 were found to be appreciably superior to 75S-T6, and failure occurred in approximately 60 seconds under a stress of 11,000 psi. The two alloys were approximately equal in their load carrying ability at 550°F, since they both withstood a stress of 8,000 psi for approximately 60 seconds.

Contrary to common belief, this investigation shows that aluminum alloys are capable of withstanding appreciable loads of short-time duration, at temperatures up to 550°F, and therefore indicates the possibility of using these alloys for certain component parts of supersonic guided missiles, which are subjected to high temperatures due to aerodynamic heating.

The deformations measured in this investigation were not only due to compressive creep, but also were due to sidewise deflection of the column, therefore it is recommended that further research be carried on for the above alloys using specimens whose L'/ρ is in the neighborhood of 10 to 15, in order to more nearly approach true compressive creep. It is also recommended that the investigation be extended to include the magnesium alloys, such as FS-1 and ZK-60a.

Investigations should also be conducted to determine the effect of creep during heating. The specimens should be loaded and then heated rapidly to a predetermined temperature. This would simulate

the temperature conditions imposed by aerodynamic heating on a guided missile during acceleration to its maximum flight speed.

In this investigation the specimen was heated to the specified temperature and soaked for one hour prior to test, therefore it is recommended the time be shortened in definite increments, in order to determine the effect of soaking period on the creep characteristics.

Before further research is attempted the following changes in equipment are suggested:

1. Increase the power to the bottom ring element to 500 watts, and at the same time make possible the control of power to this element. It is felt this change will further decrease the gradient in the specimen.

2. If feasible, increase the field of vision of the available telescopes, or purchase new ones.

3. Use a screw-type jack rather than hydraulic, for applying the load to the specimen. A screw-type automobile jack would serve the purpose very well. It is believed the rate of loading could be better regulated with this type jack.

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TABLE [illegible]

Room Temperature Mechanical Properties of 75S-T6 and 25S-T6 Specimens.

	75S-T6	25S-T6
Ultimate Tensile Strength - psi	84,800	58,700
Tensile Yield Strength (0.2 percent Offset)	76,500	[illegible]0,450
Modulus of Elasticity (Tension)-psi	10.27×10^6	10.61×10^6
Compressive Yield Strength (0.2 percent Offset)	81,000	[illegible]3,000
Modulus of Elasticity (Compression)-psi	10.6×10^6	10.61×10^6
Elongation (percent in 2 inches)	10.0	8.0

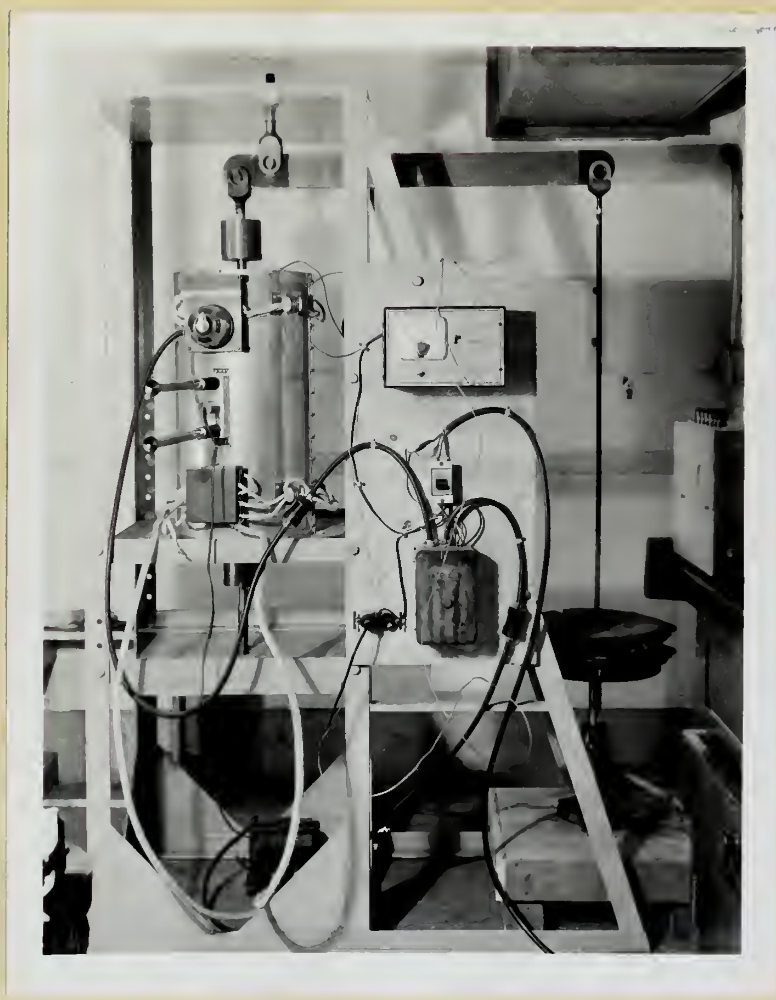


Fig. 1 Test Apparatus

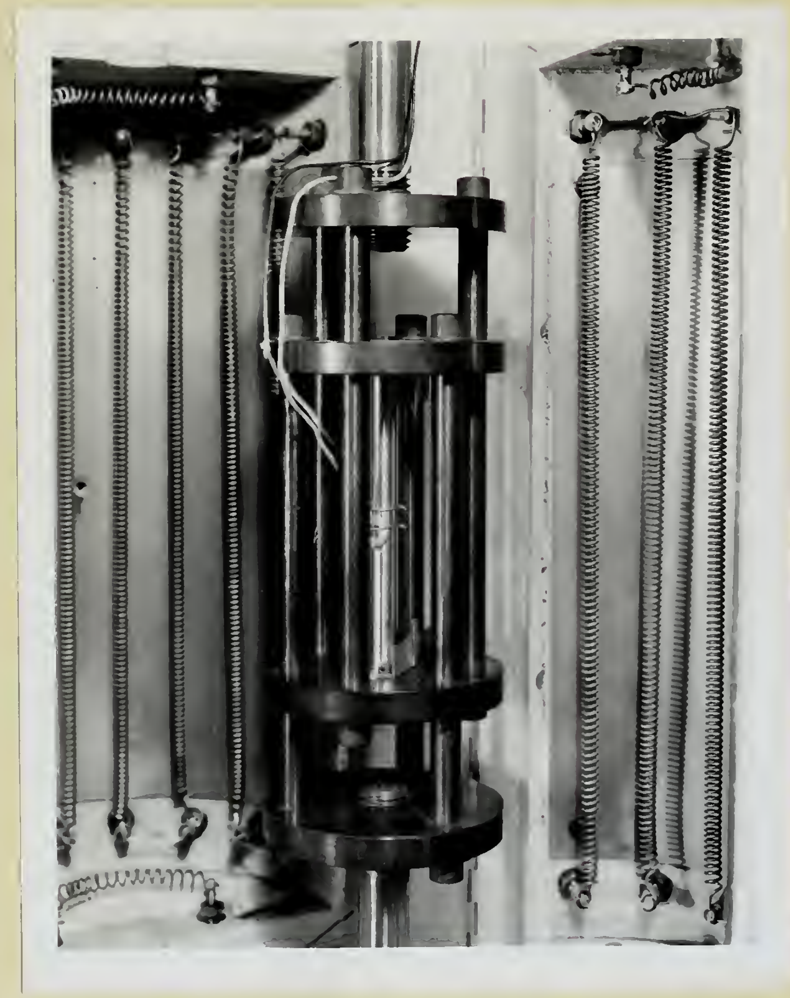
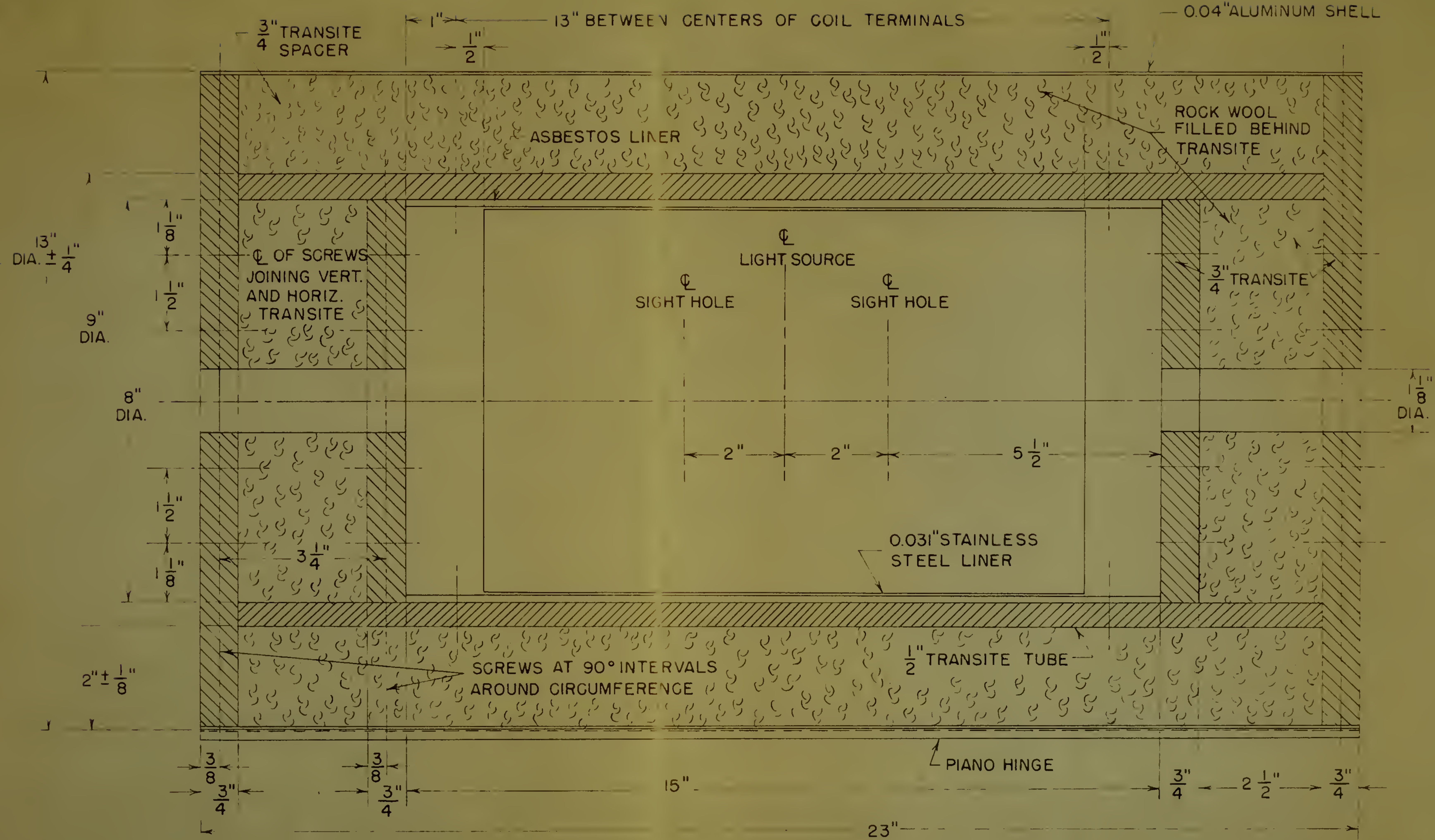


Fig. 2 Reversing Cage and Scales.

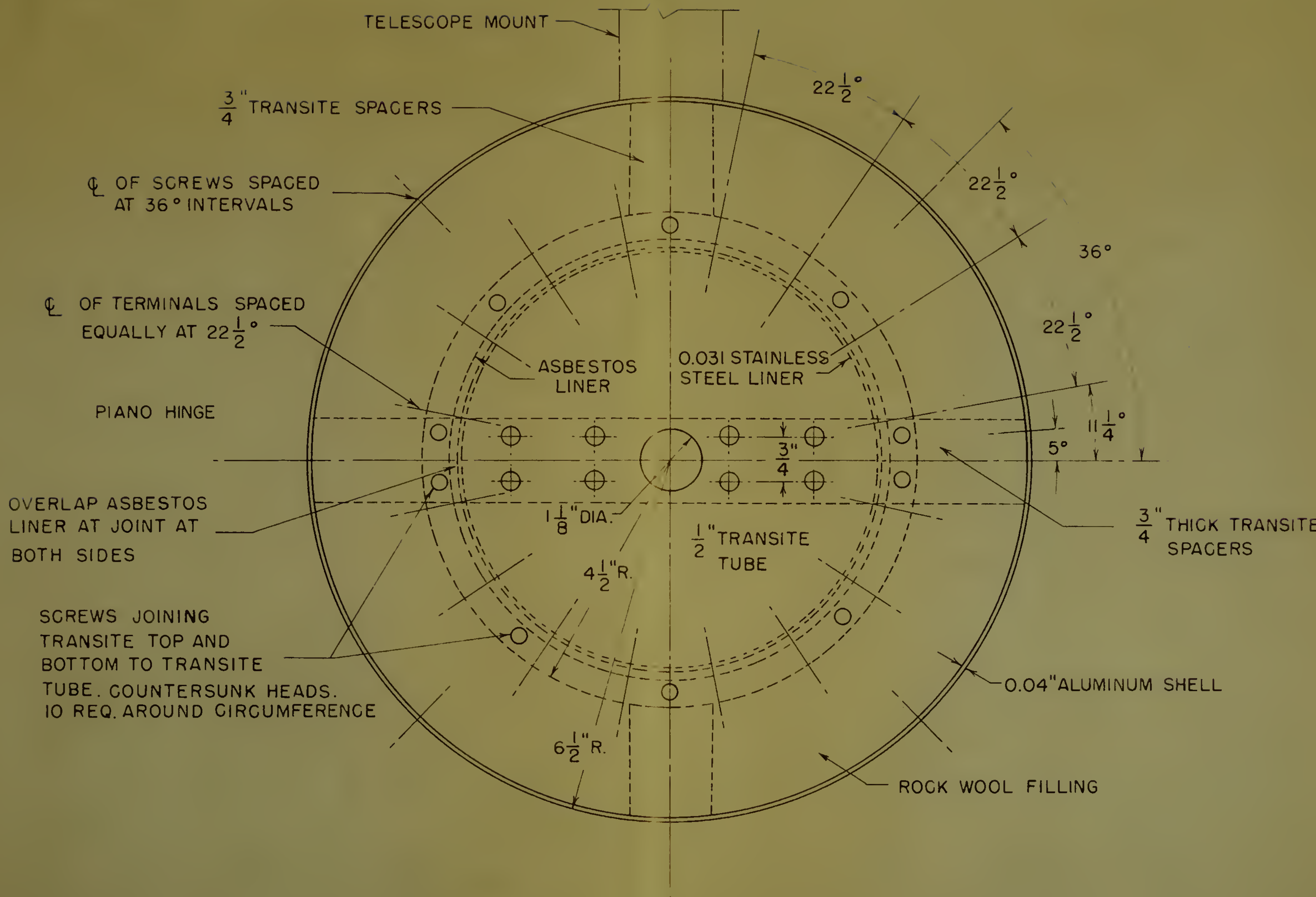


NOTES:

1. FURNACE TO BE BUILT IN TWO HALVES. USE $\frac{3}{4}$" TRANSITE SHEET AT DIVIDING LINE TO CLOSE IN ROCK WOOL FILLER.
2. STAINLESS STEEL LINER TO BE FITTED WITH OVERSIZE HOLES AT FASTENING POINTS TO ALLOW FOR EXPANSION.
3. MANNER OF SCREWING TRANSITE TOGETHER IS IDENTICAL AT TOP AND BOTTOM OF FURNACE.

FRONT VIEW
CREEP TEST FURNACE

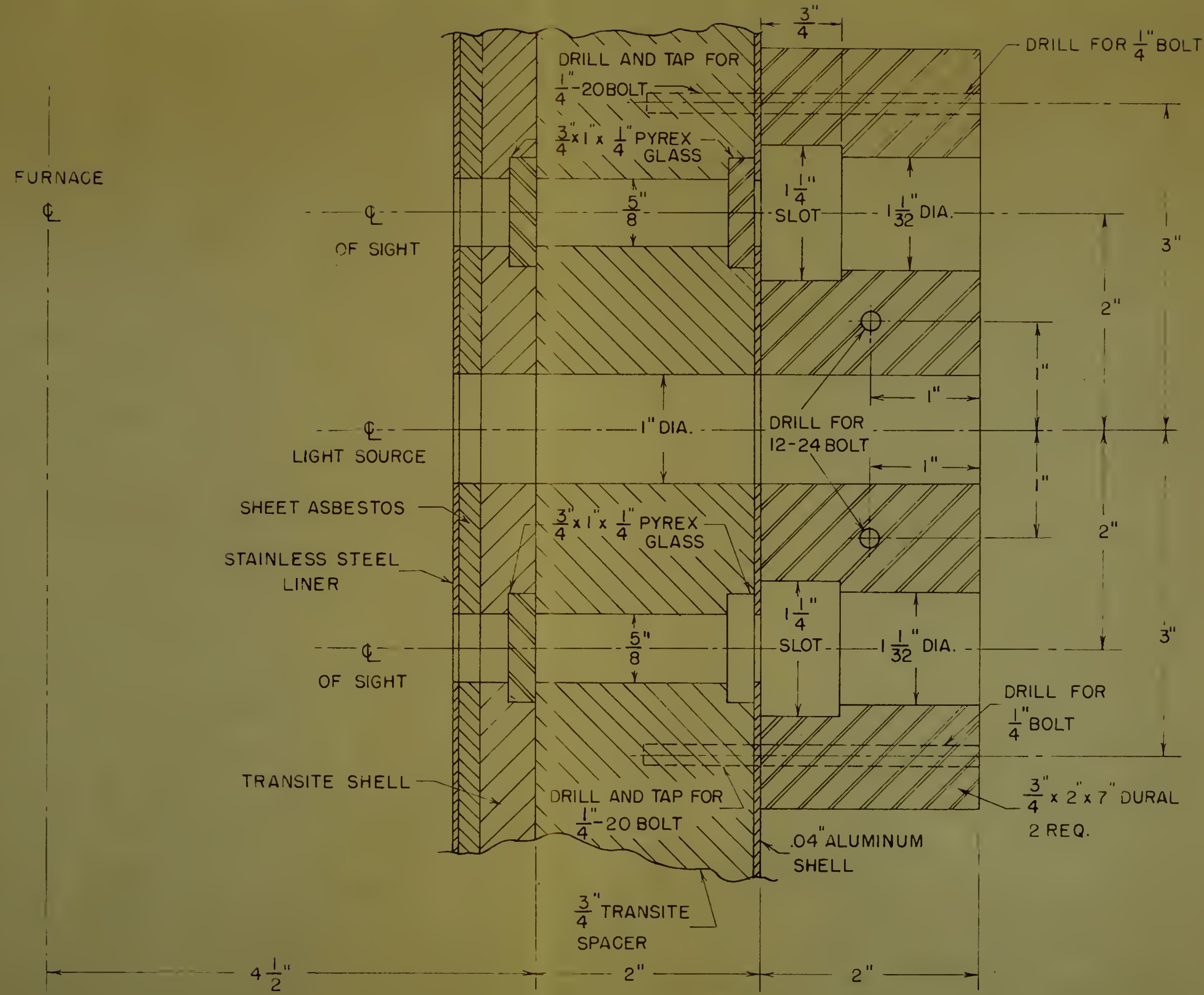
FIG. 3



TOP VIEW

CREEP TEST FURNACE

FIG. 4



DETAILS OF WINDOWS AND TELESCOPE MOUNT
FOR CREEP TEST FURNACE

FIG. 5

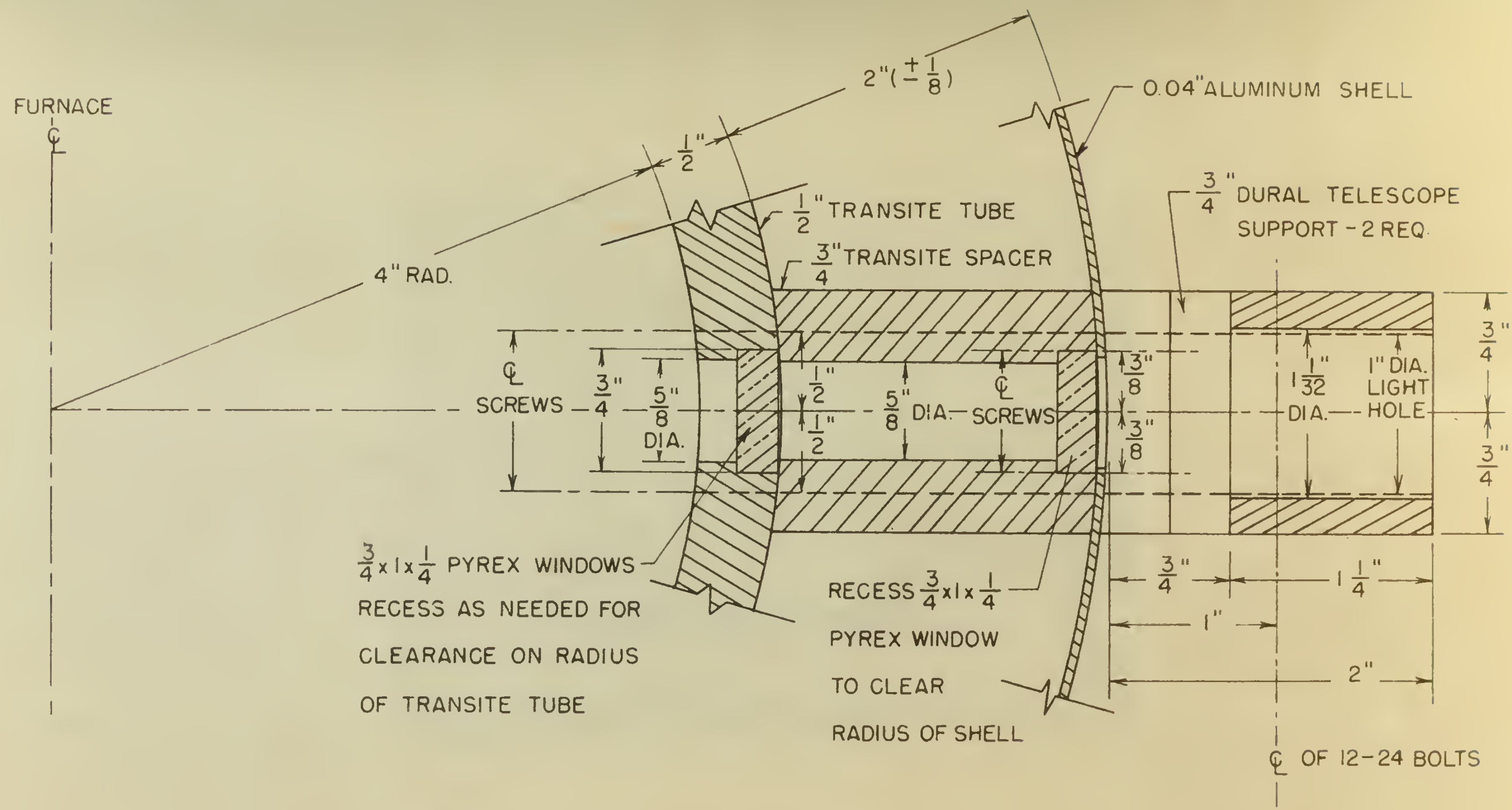


FIG. 6

HORIZONTAL SECTION THROUGH CENTER LINE OF TELESCOPE

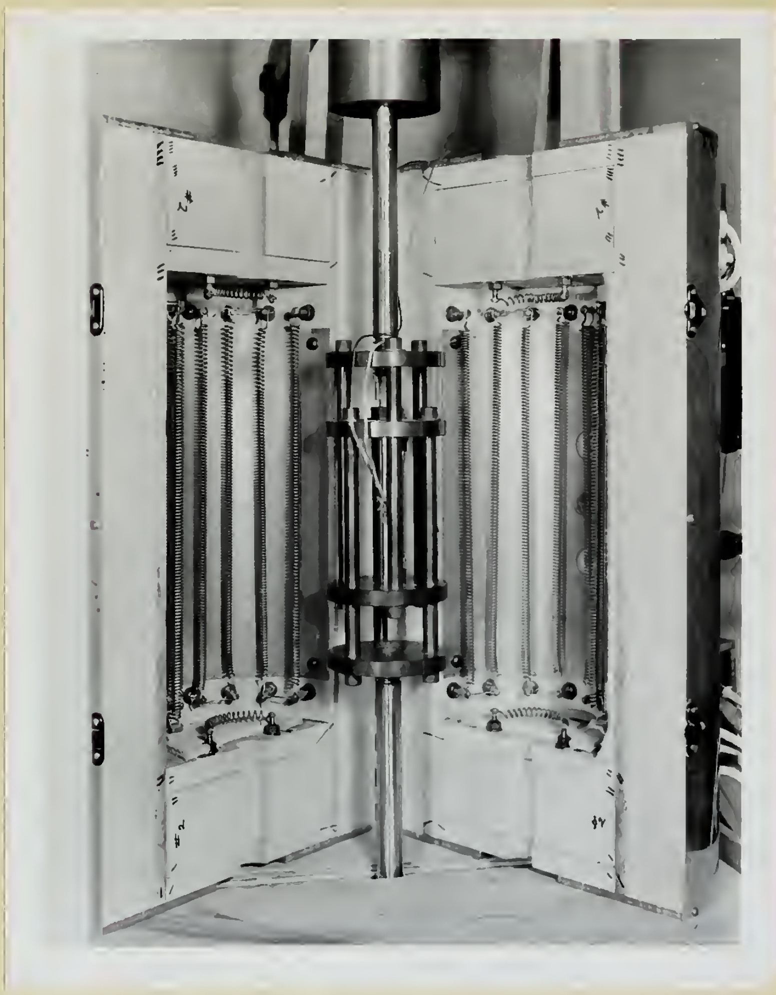
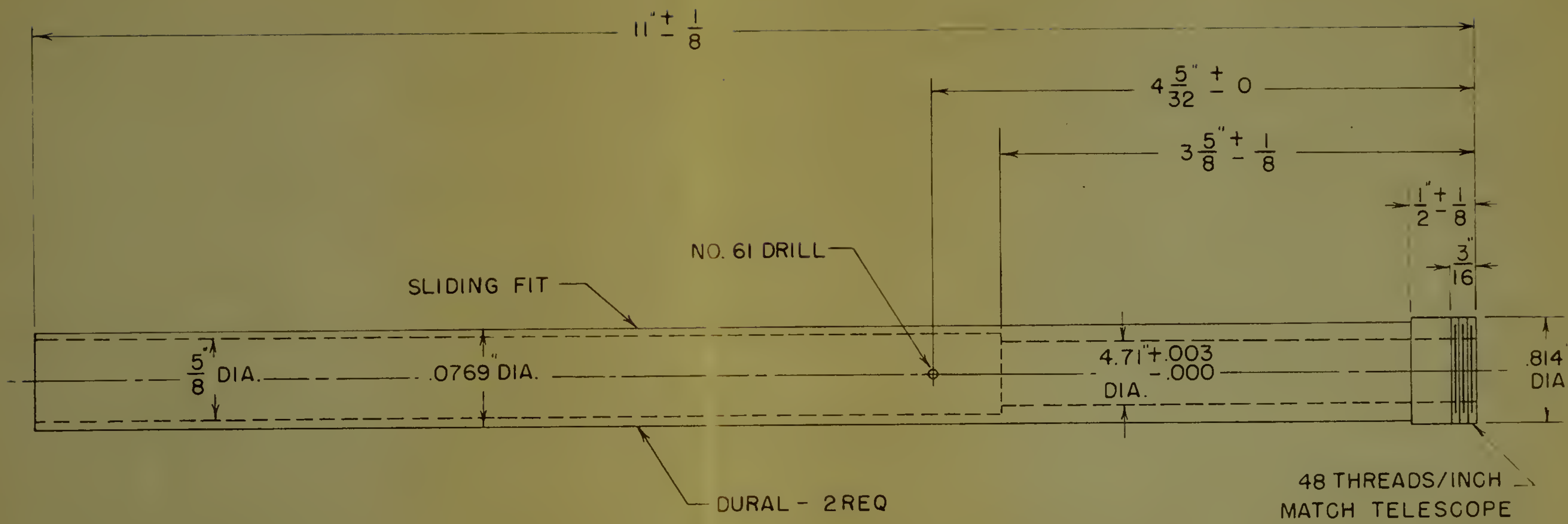
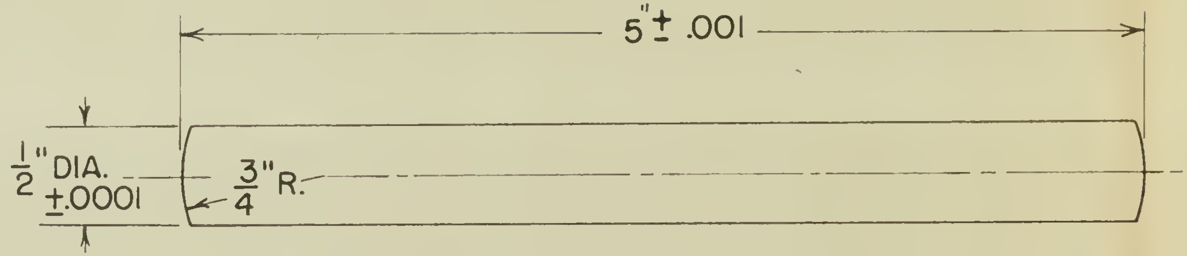


Fig. 7 Inside of Furnace



EXTENSION FOR WALLENSAK TELESCOPE

FIG. 8



ENDS ARE SPHERICAL

FIG. 9
COMPRESSION TEST SPECIMEN

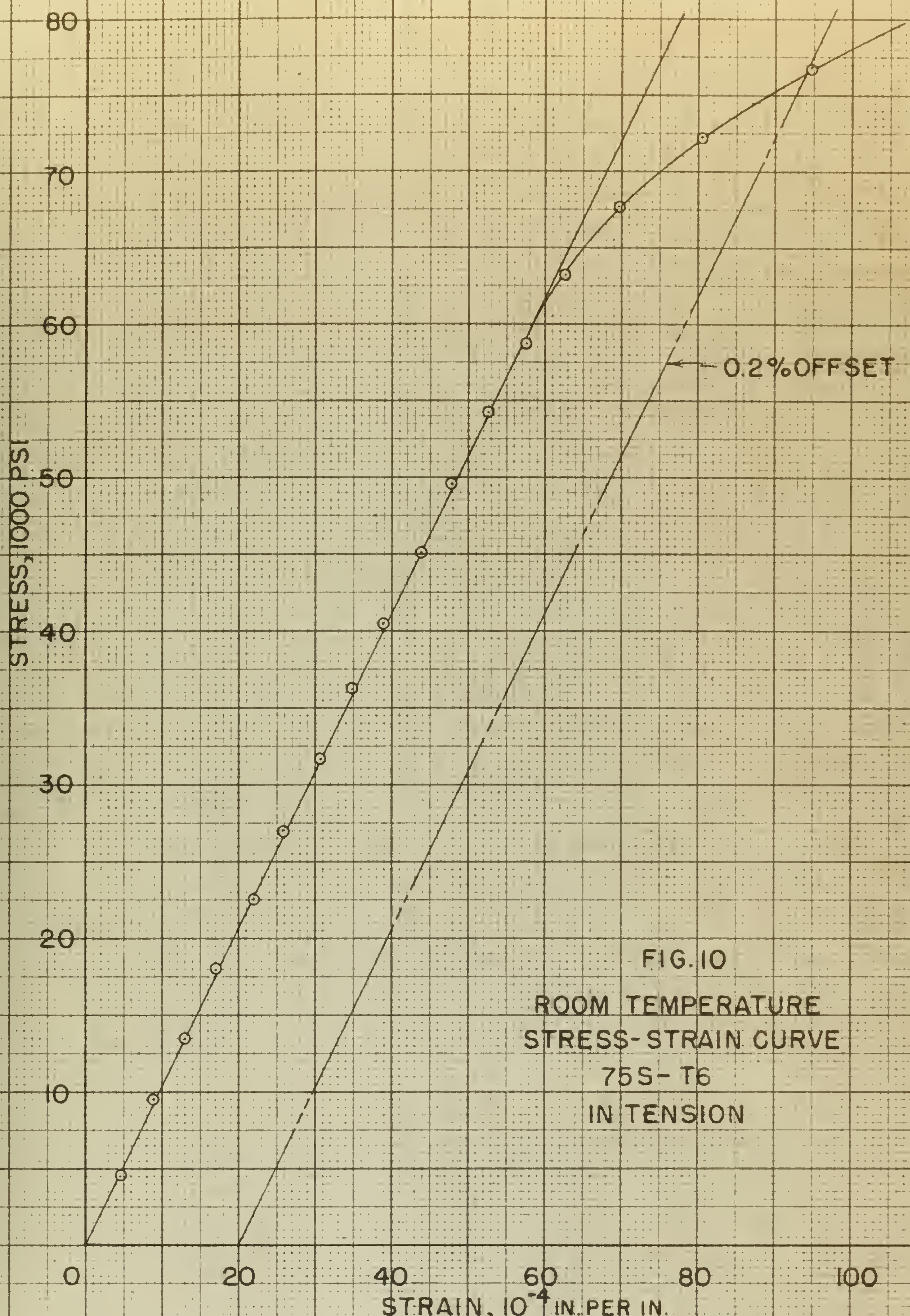


FIG. 10
ROOM TEMPERATURE
STRESS-STRAIN CURVE
75S-T6
IN TENSION

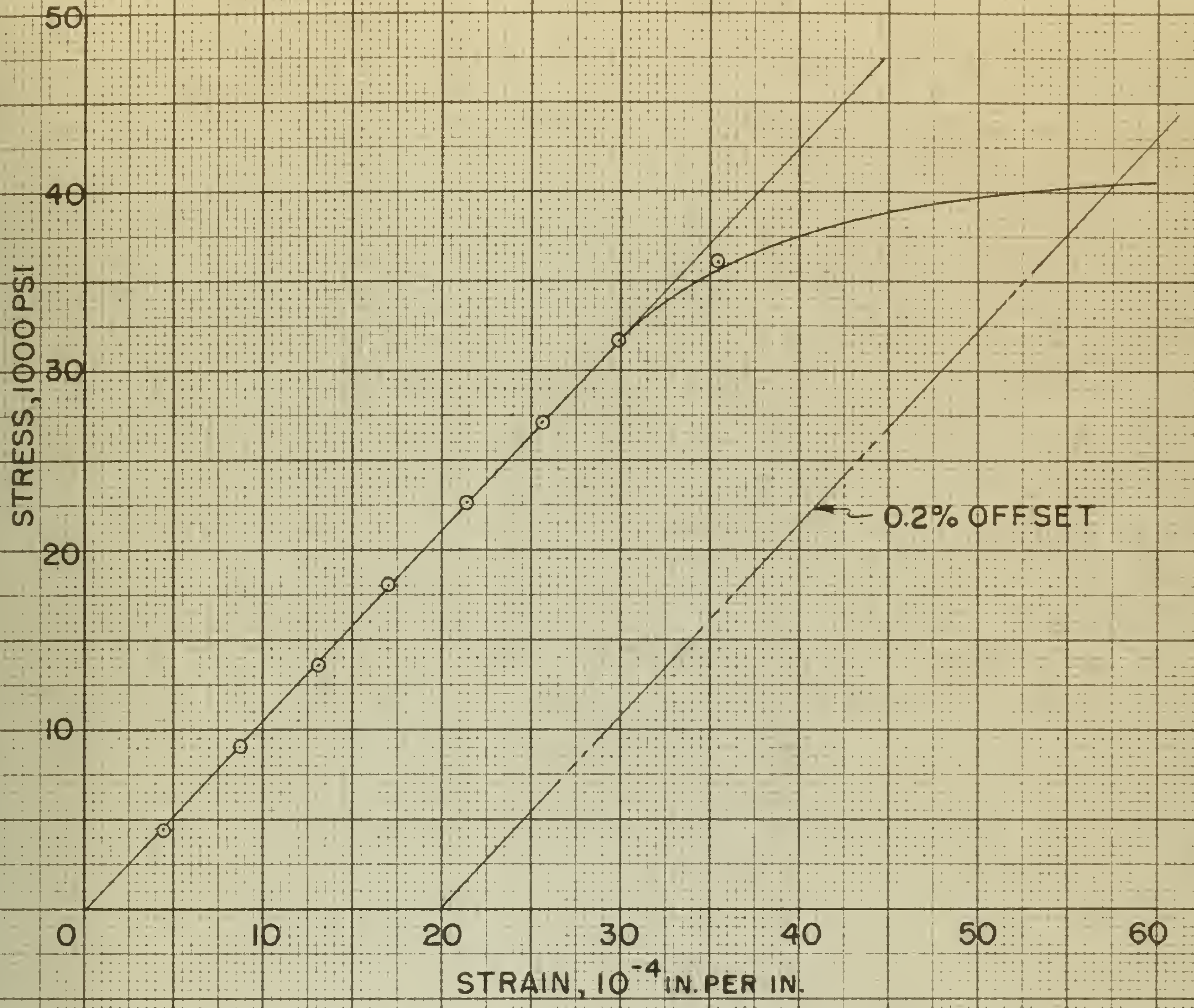


FIG. 11

ROOM TEMPERATURE STRESS-STRAIN CURVE
FOR 25S-T6
IN TENSION

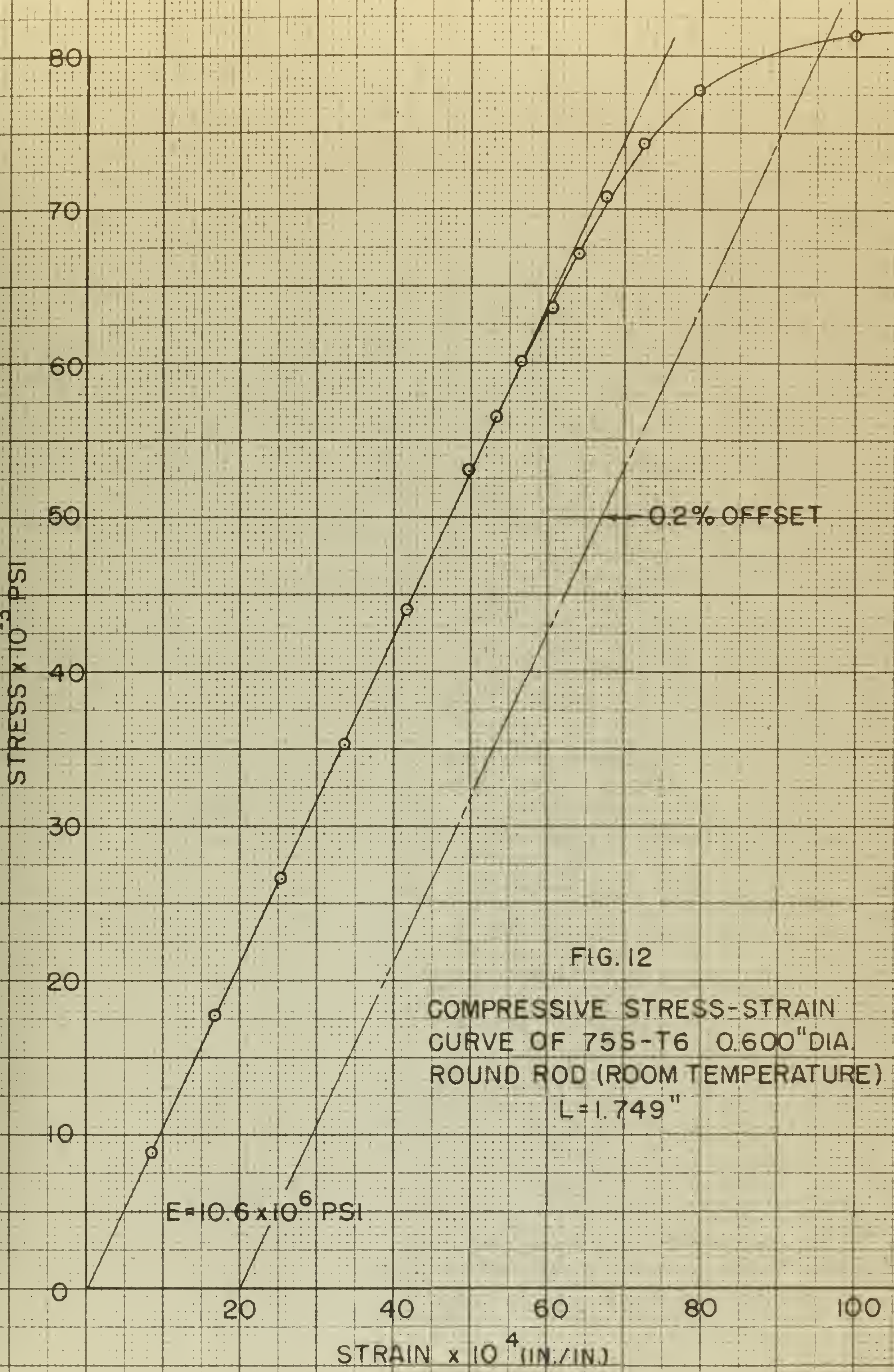


FIG. 12

COMPRESSIVE STRESS-STRAIN CURVE OF 75S-T6 0.600"DIA. ROUND ROD (ROOM TEMPERATURE)
L=1.749"

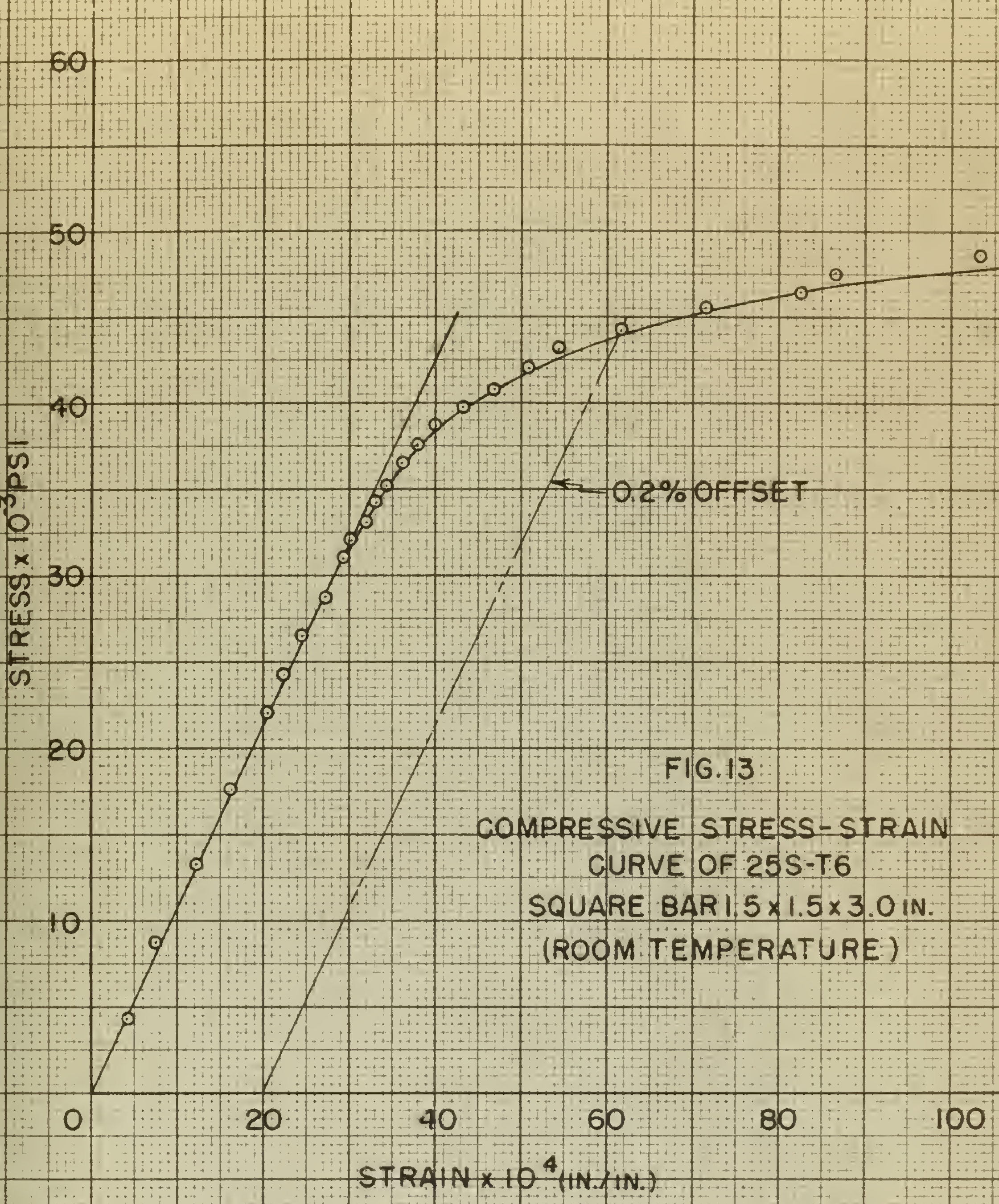


FIG. 13

COMPRESSIVE STRESS-STRAIN CURVE OF 25S-T6
SQUARE BAR 1.5 x 1.5 x 3.0 IN.
(ROOM TEMPERATURE)

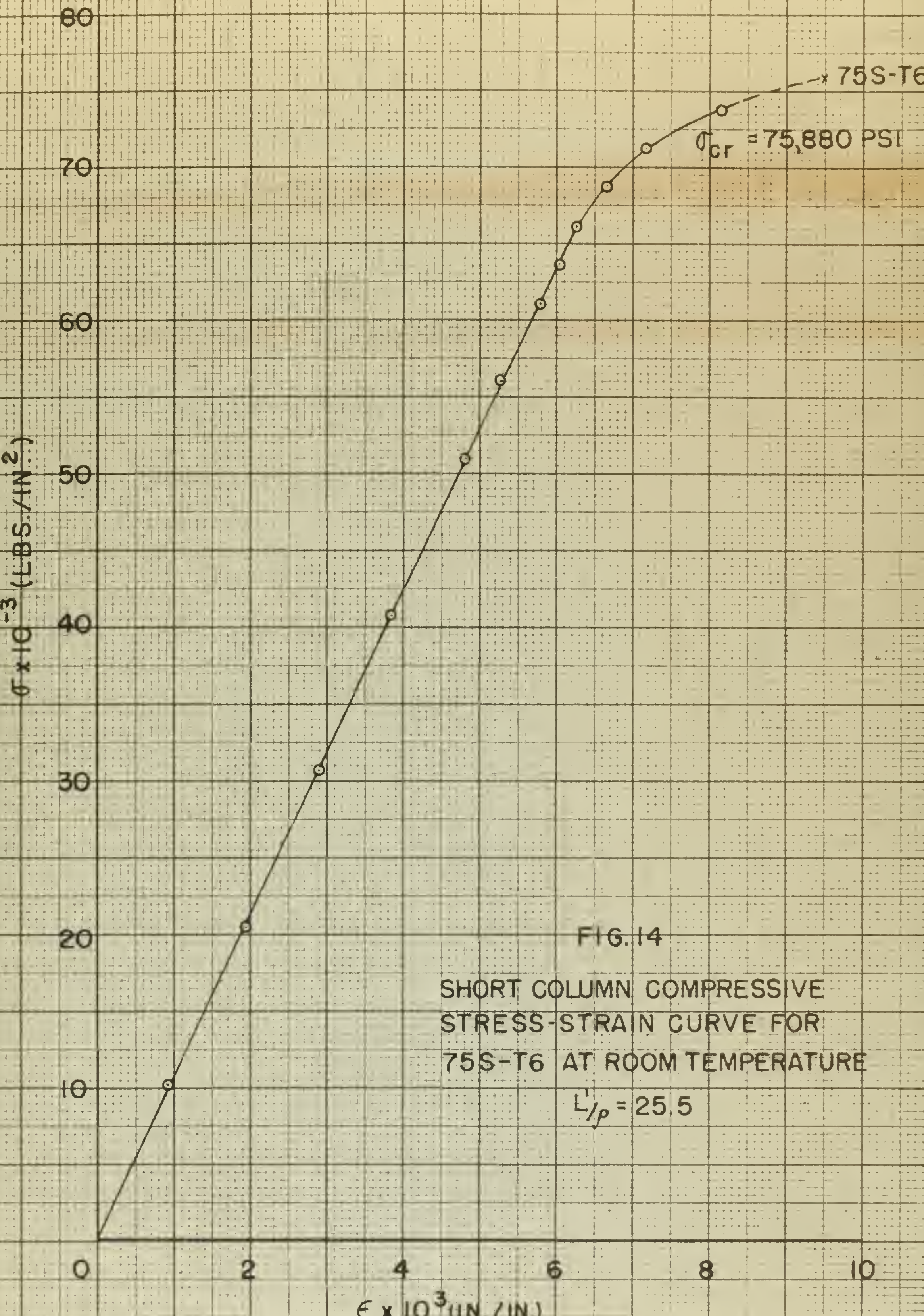


FIG. 14

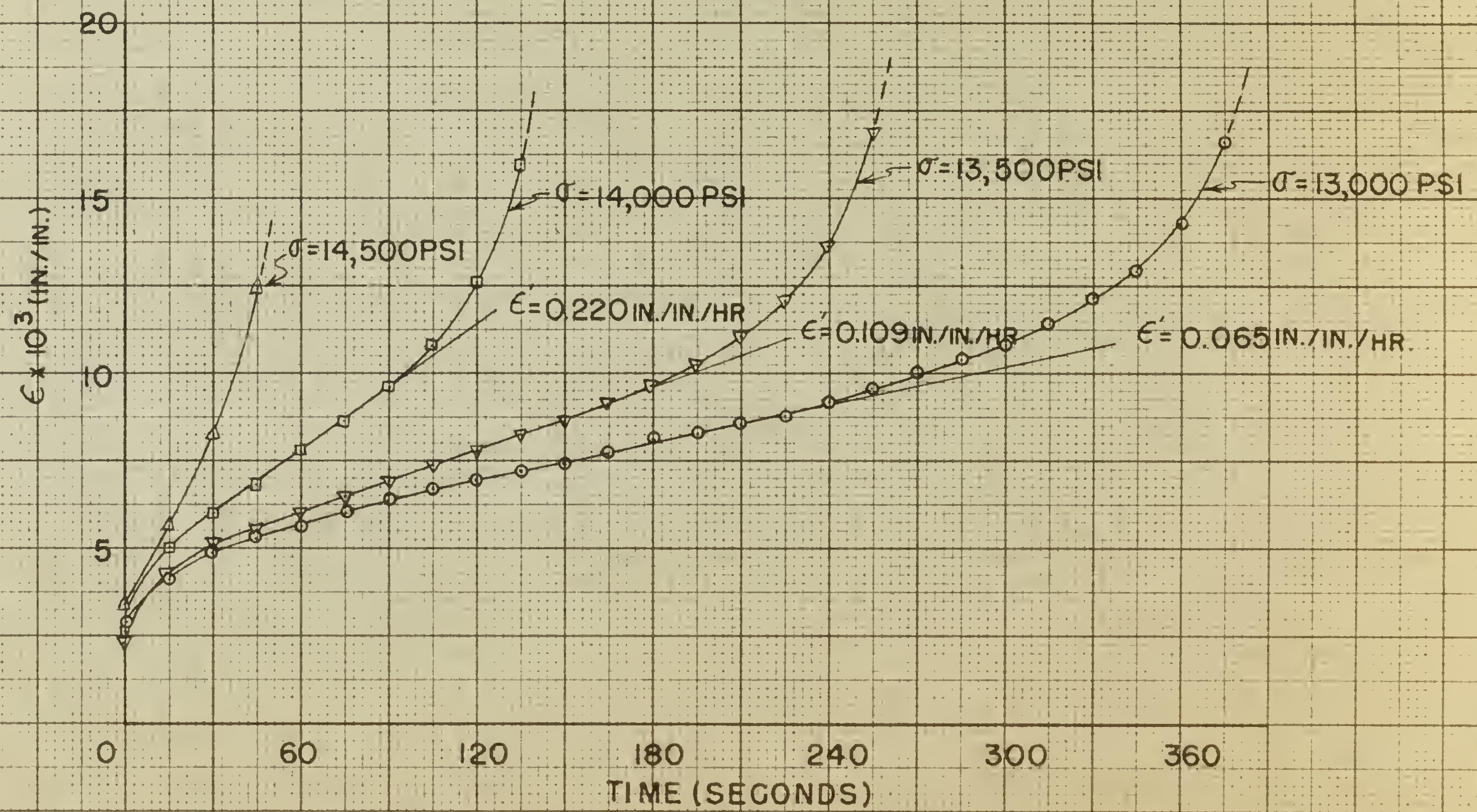
SHORT COLUMN COMPRESSIVE STRESS-STRAIN CURVE FOR 75S-T6 AT ROOM TEMPERATURE

$L'/\rho = 25.5$

FIG. 15

COMPRESSIVE CREEP IN 75S-T6 SHORT COLUMNS, STABILIZED ONE HOUR AT 450°F

$L'/\rho = 25.5$



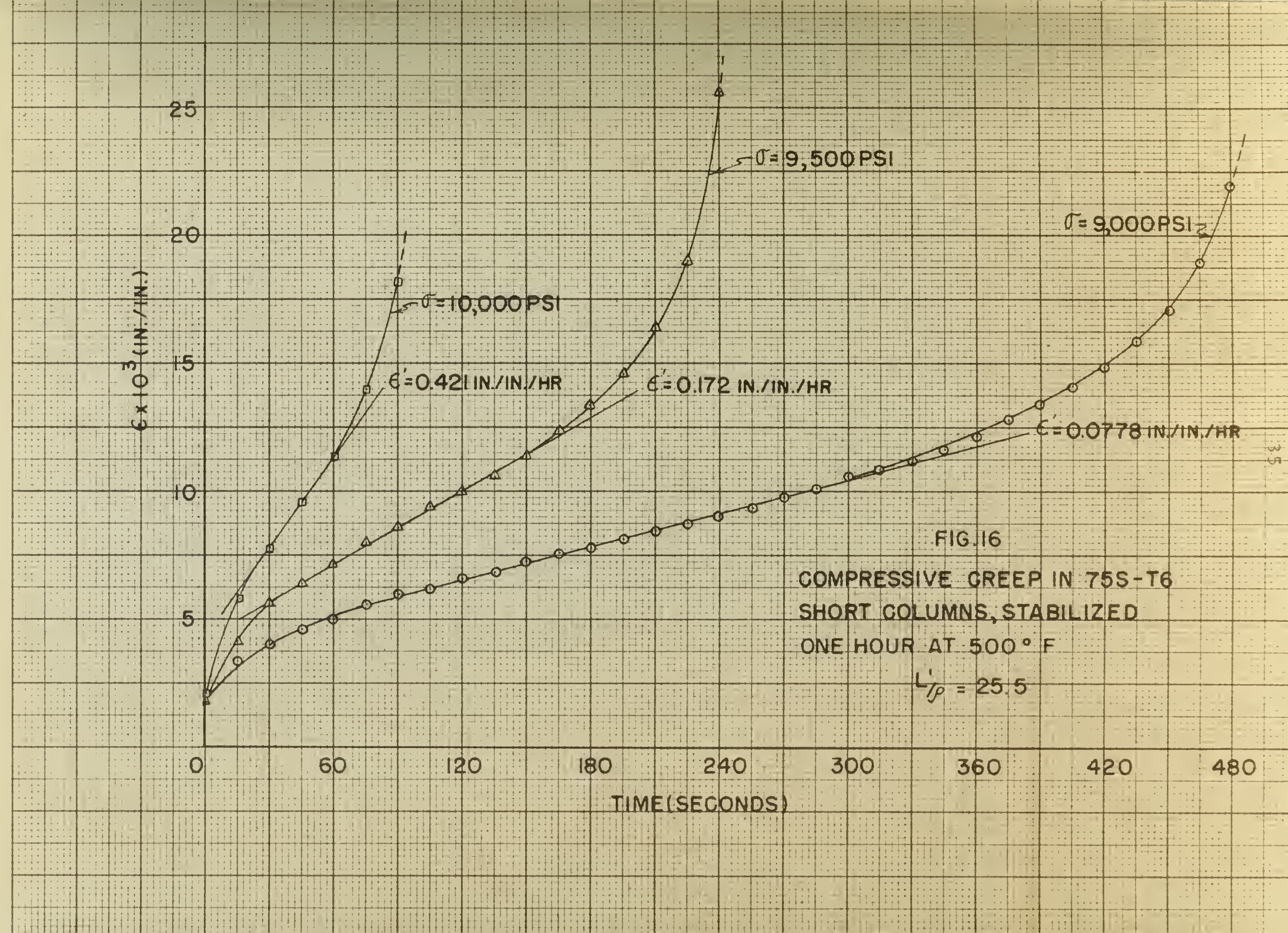


FIG. 16

COMPRESSIVE CREEP IN 75S-T6
SHORT COLUMNS, STABILIZED
ONE HOUR AT 500° F
$L'/\rho = 25.5$

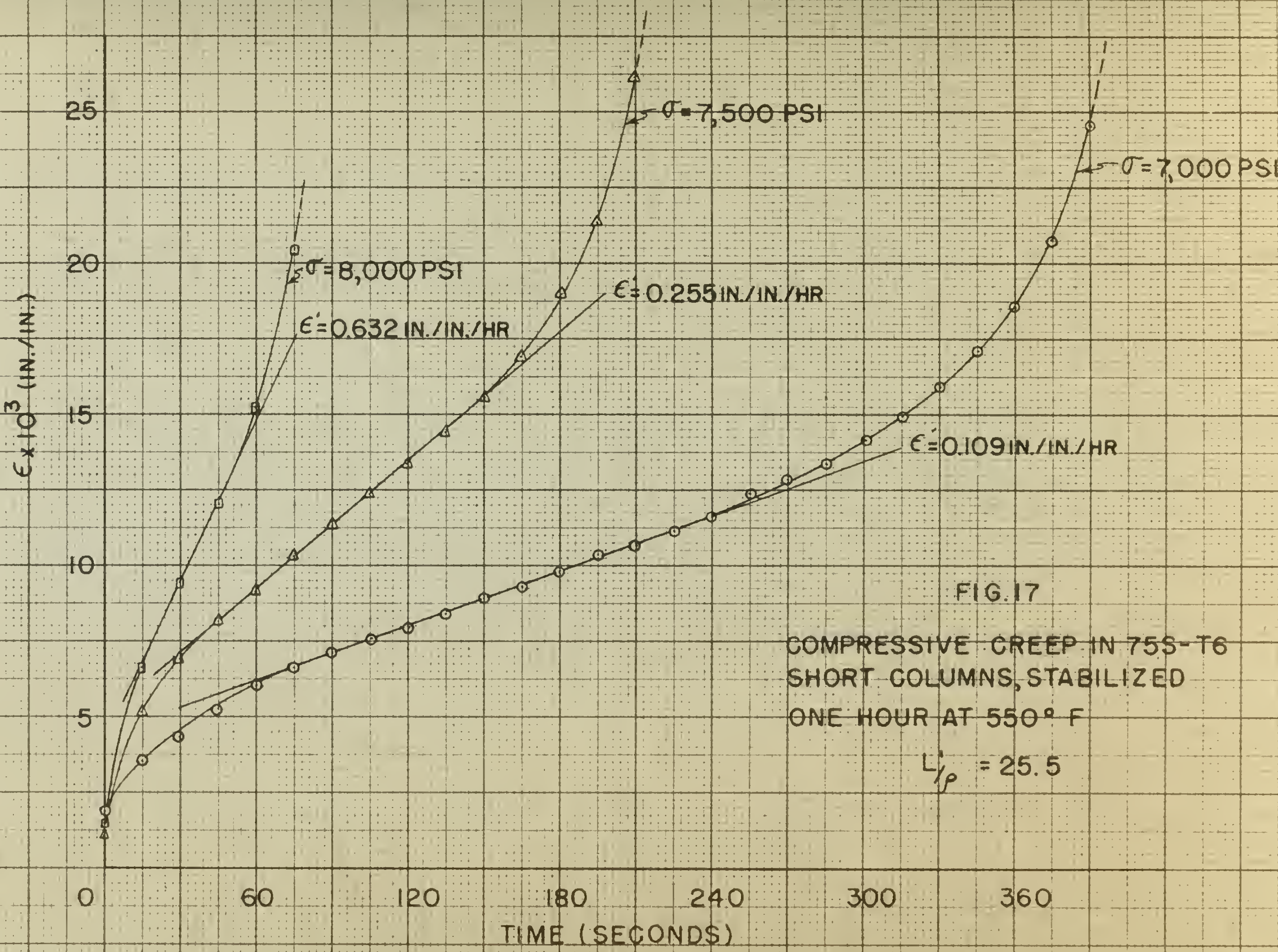


FIG. 17

COMPRESSIVE CREEP IN 75S-T6
SHORT COLUMNS, STABILIZED
ONE HOUR AT 550° F

$L'/\rho = 25.5$

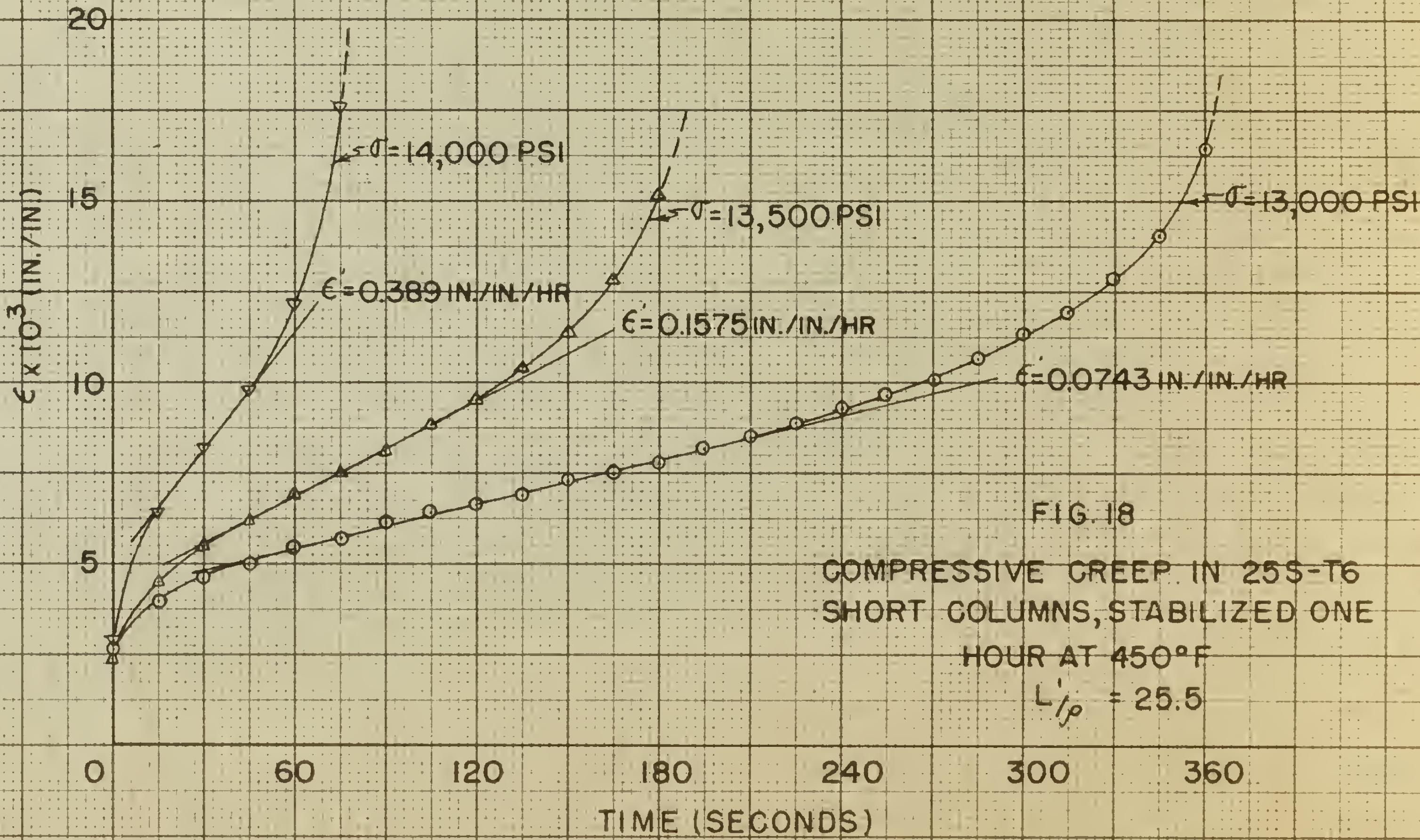


FIG. 18

COMPRESSIVE CREEP IN 25S-T6 SHORT COLUMNS, STABILIZED ONE HOUR AT 450°F

$L'/\rho = 25.5$

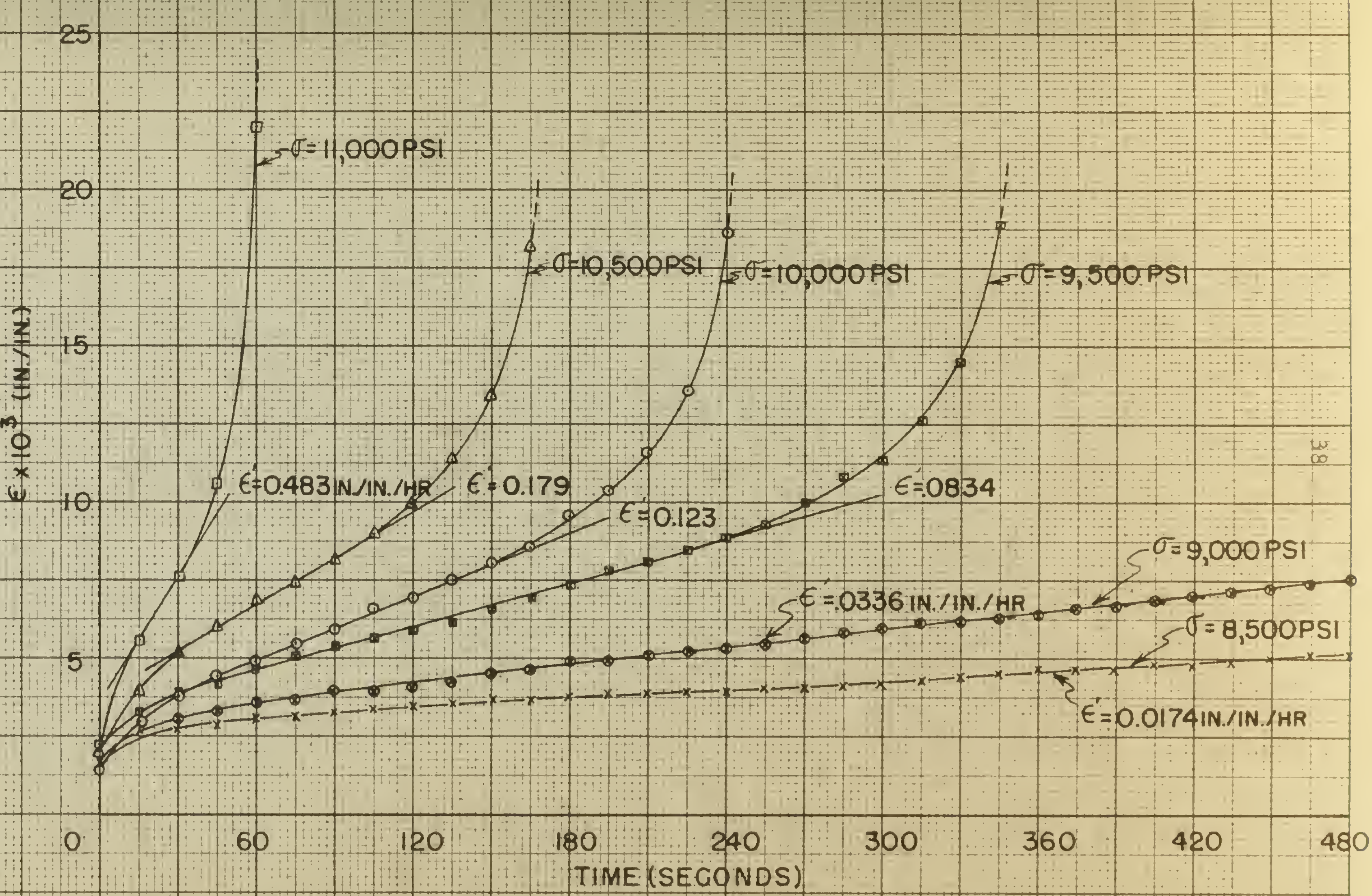


FIG. 19 COMPRESSIVE CREEP IN 25S-T6 SHORT COLUMNS, STABILIZED ONE HOUR AT 500° F $L'/\rho = 25.5$

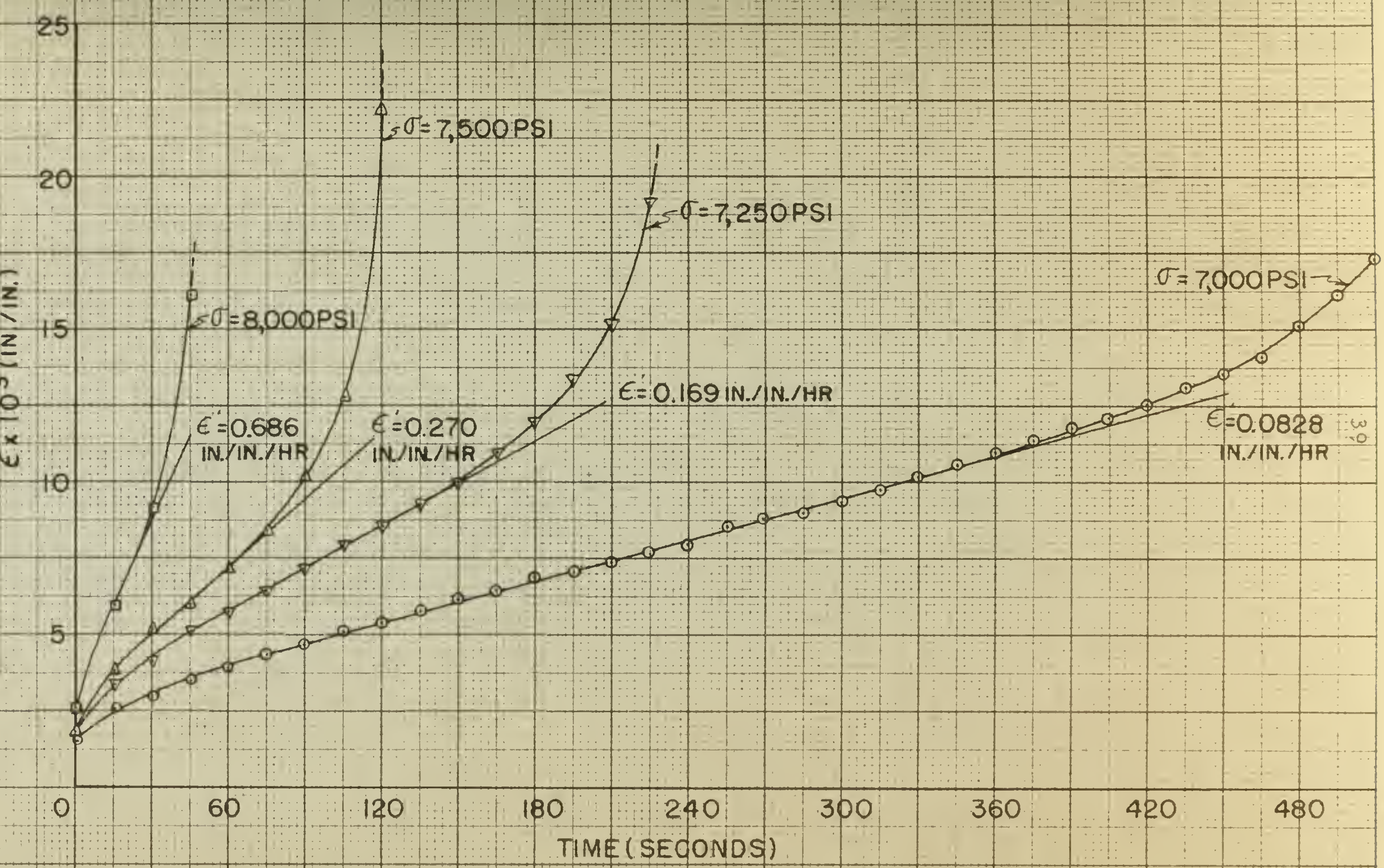


FIG. 20 COMPRESSIVE CREEP IN 25S-T6 SHORT COLUMNS, STABILIZED ONE HOUR AT 550° F L'/ρ = 25.5

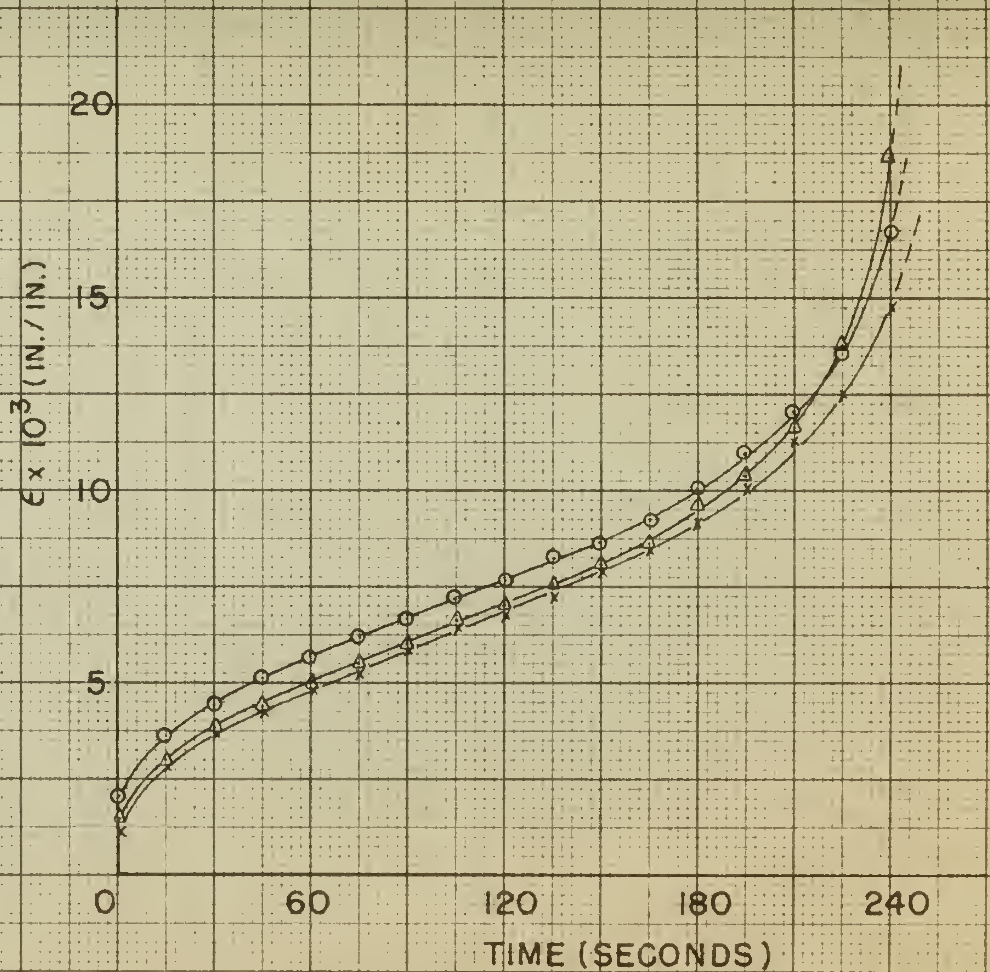


FIG. 21

REPRODUCILIBILITY OF DATA ; COMPRESSIVE CREEP OF THREE 25S-T6 SHORT COLUMNS $\sigma = 10{,}000$ PSI ; $T = 500°$ F ; $L/\rho = 25.5$

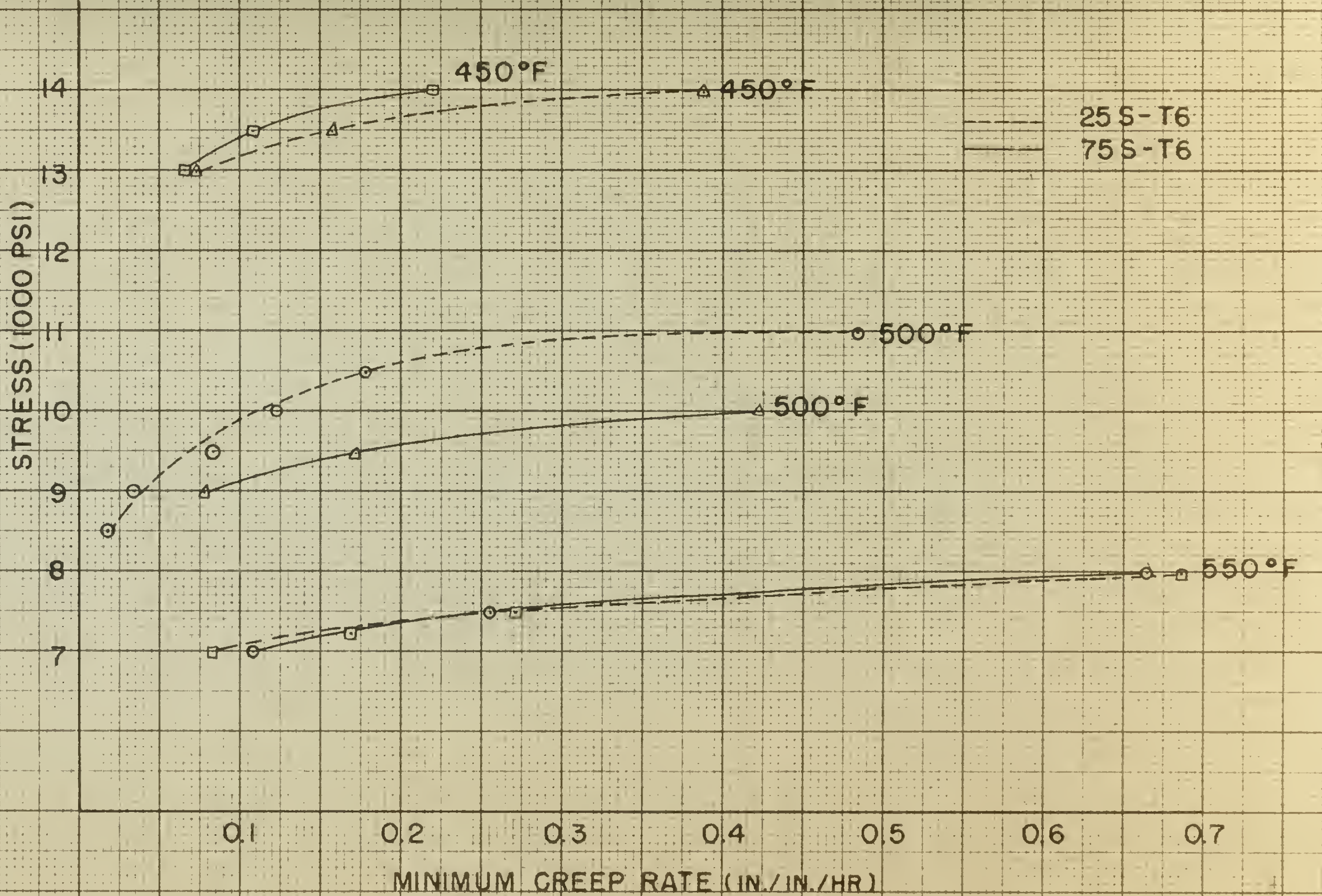


FIG. 22

MINIMUM CREEP RATE vs STRESS FOR 25S-T6 AND 75S-T6

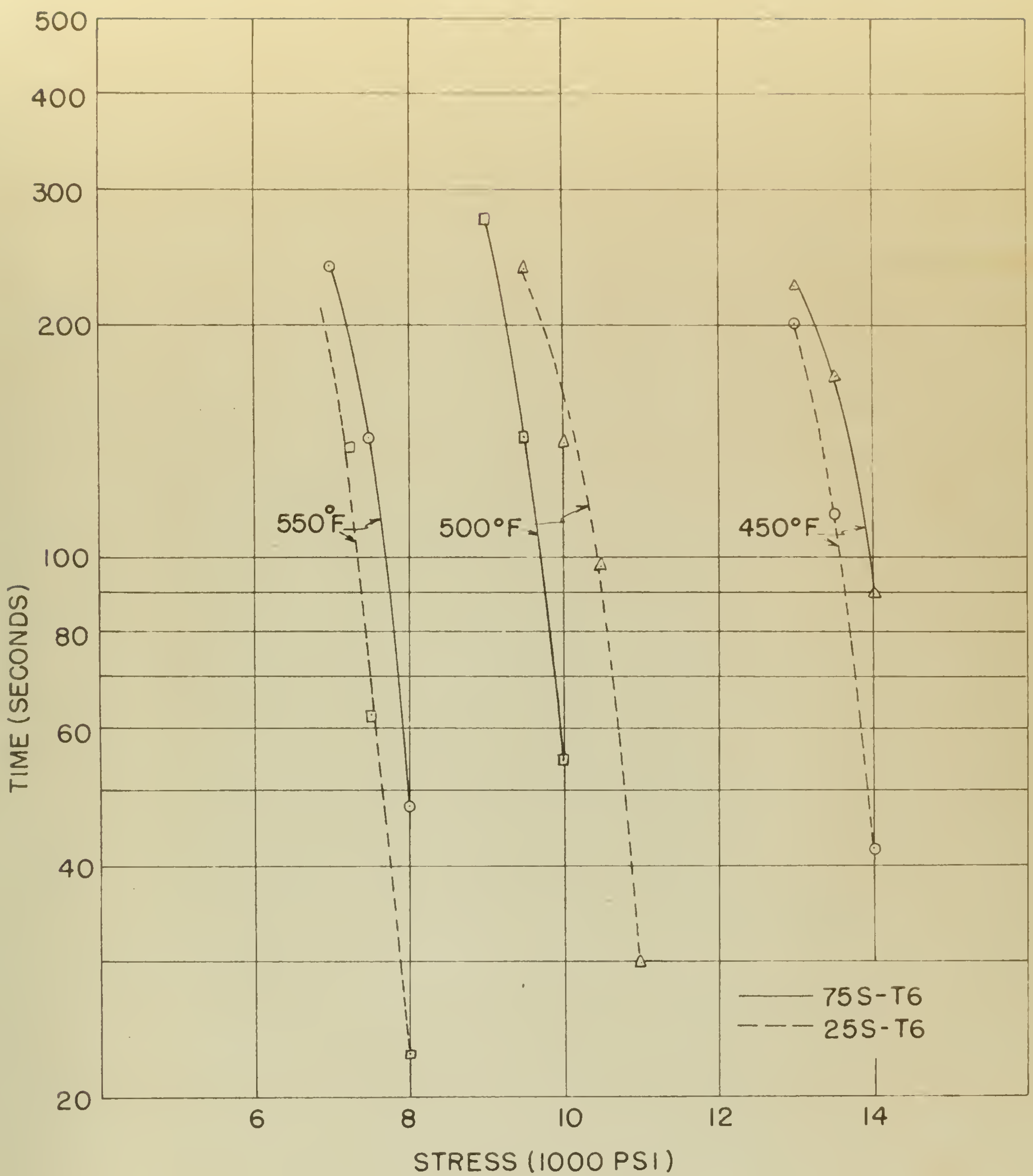


FIG. 23

TIME TO TRANSITION POINT FOR 75S-T6 AND 25 S-T6 SHORT COLUMNS, STABILIZED ONE HOUR AT TEMPERATURE

$L'/\rho = 25.5$

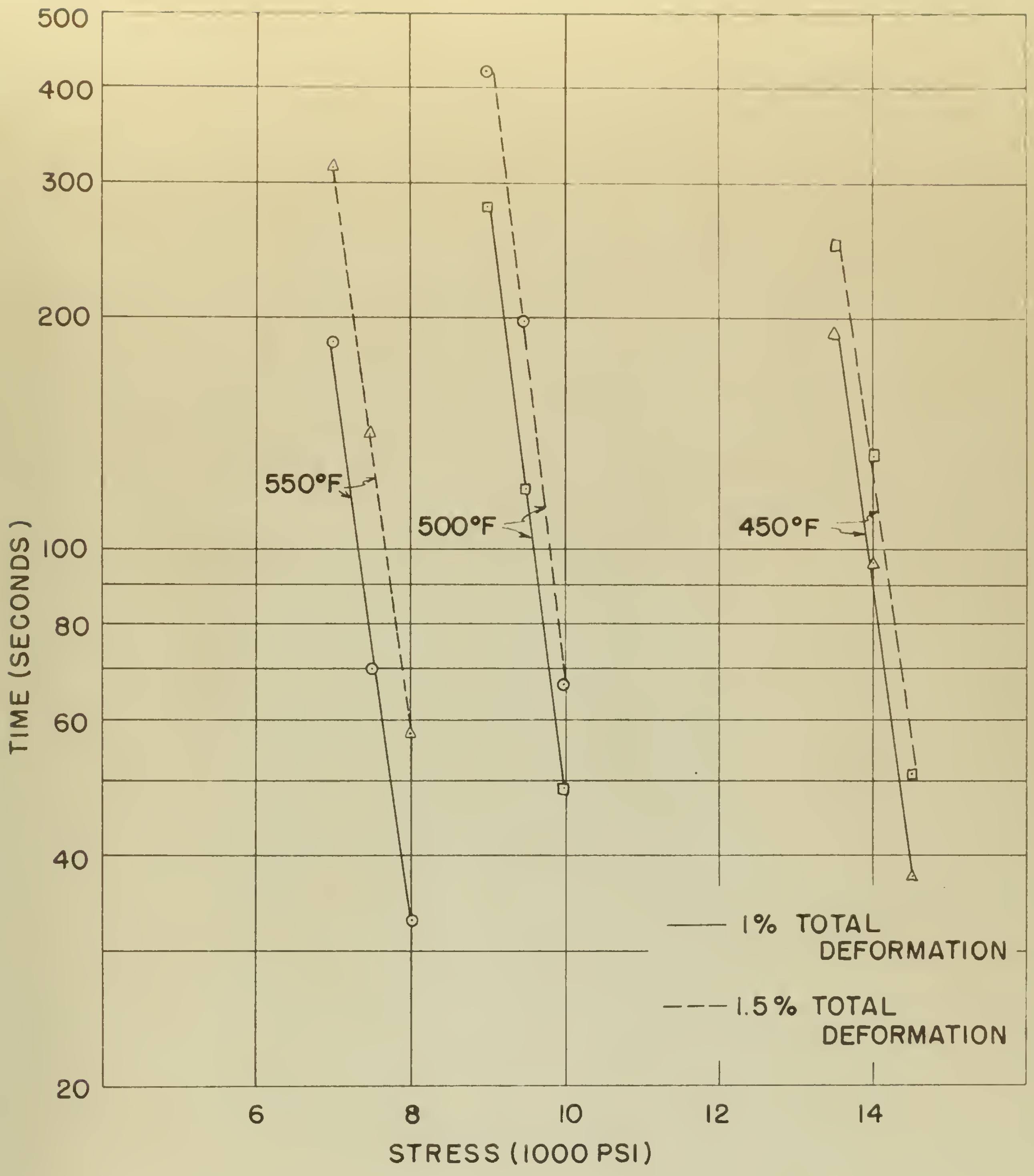


FIG. 24

TIME REQUIRED FOR 1% AND 1.5% TOTAL DEFORMATION IN 75S-T6 SHORT COLUMNS, STABILIZED ONE HOUR AT TEMPERATURE $L'/\rho = 25.5$

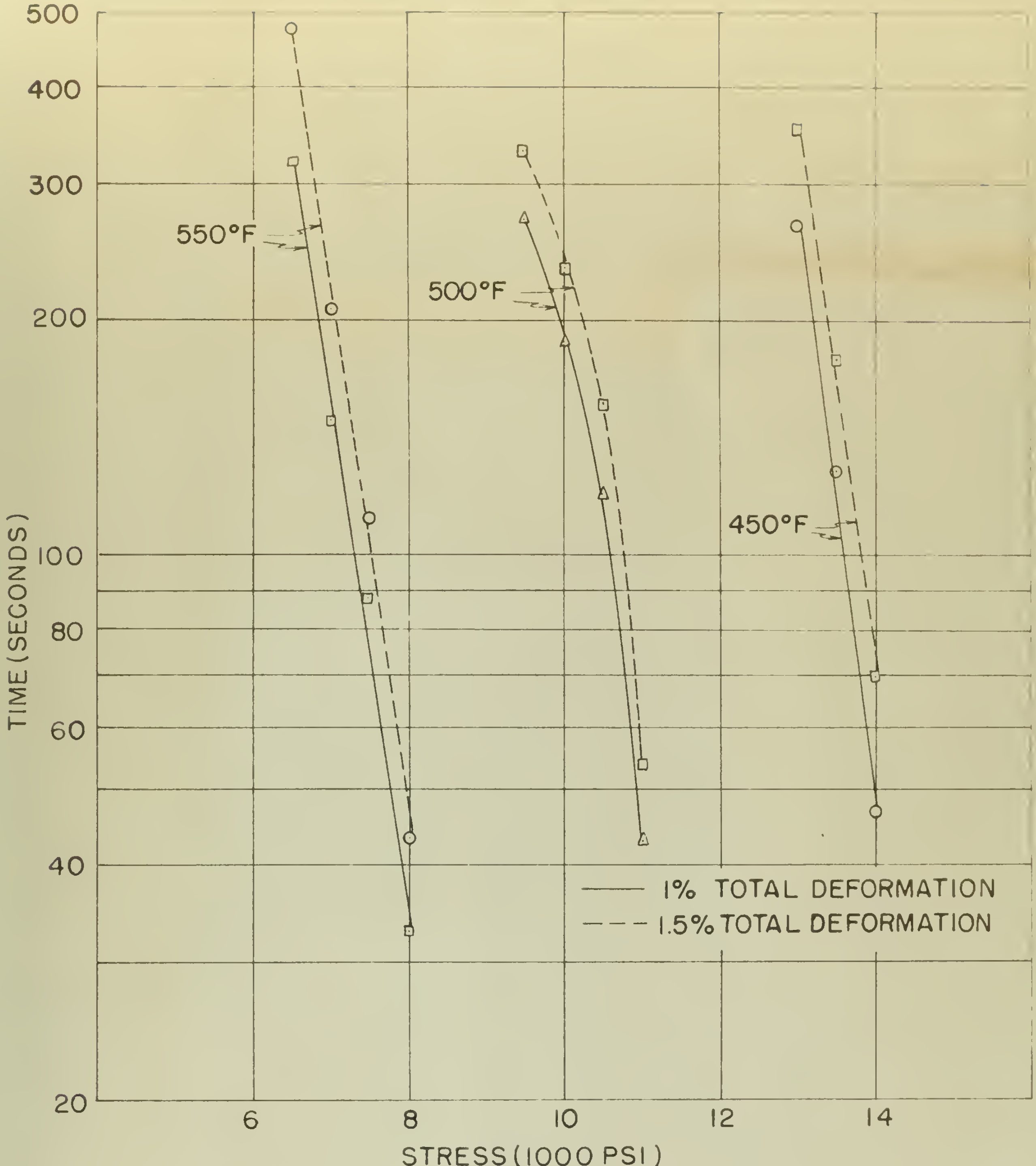


FIG. 25

TIME REQUIRED FOR 1% AND 1.5% TOTAL DEFORMATION IN 25S-T6 SHORT COLUMNS, STABILIZED ONE HOUR AT TEMPERATURE

$L'/\rho = 25.5$